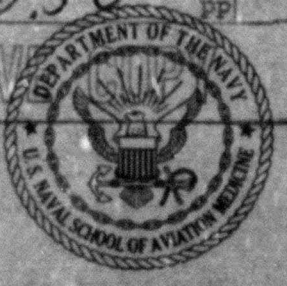
RESIDUAL EFFECTS OF STORM CONDITIONS AT SEA UPON THE POSTURAL EQUILIBRIUM FUNCTIONING OF VESTIBULAR NORMAL AND VESTIBULAR DEFECTIVE HUMAN SUBJECTS

Alfred R. Fregly and Ashton Graybiel

JOINT REPORT



UNITED STATES NAVAL SCHOOL OF AVIATION MEDICINE
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U.S. NAVAL AVIATION MEDICAL CENTER
PENSACOLA, FLORIDA

SUMMARY PAGE

THE PROBLEM

The residual effects of storm conditions at sea upon postural equilibrium functioning have not been studied objectively. As part of a larger study, the opportunity was taken to investigate, by means of a new quantitative ataxia test battery, these effects in vestibular normals (N=20) and labyrinthine defective (L-D) human subjects (N=9).

FINDINGS

Following the highly stressful sea experience, during which bizarre stimulation of the vestibular apparatus was amply provided, the L-D group maintained or improved their baseline postural equilibrium test performance scores, whereas some normals did and some normals did not show postural decrement. Application of the split-half method of analysis revealed that these differential effects within the normal group were partly attributable to initial (baseline) levels of performance; i.e., the ten initially poorest scoring normals as a sub-group were free of postural decrement in contrast with significant performance decrements observed in the highest scoring sub-group of normals. Other influences on differential results within the normals and between groups as well as differential test findings are discussed.

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INTRODUCTION

Residual effects of bizarre stimulation of the vestibular organs by means of a sea voyage upon changes in postural equilibrium functioning (ataxia) have not yet been objectively studied. An opportunity arose for such an objective study when the symptomatology of normal persons and of labyrinthine defective (L-D) subjects under storm conditions at sea was investigated (15). A new quantitative ataxia Test Battery and related clinical-type ataxia tests recently developed in this laboratory (8) provided the means whereby such residual effects on postural equilibrium could be studied.

BACKGROUND

Bizarre stimulation of the subjects' vestibular organs was provided during early February by means of a 145-foot long tug (former U. S. Army transport) travelling the 200-mile distance between St. Pierre/Michelon, off the coast of Newfoundland, and North Sydney, Nova Scotia, over a twenty-eight-hour period during a storm. Sea conditions ranged from moderate to severe and were characterized during the first eight hours by 40-foot waves, 40-knot winds, and 80-knot gusts. The ship endured > 40 degrees of roll, a roll rate of > 10 degrees/second, and scend of > 3G as indicated by acceleration recordings.

PROCEDURE

SUBJECTS

The L-D group was comprised of nine* men, 20 to 47 years of age (mean 30.3 years), who have participated in several previous vestibular research projects at this laboratory (1-9, 11-15, 18-20). They have shown repeated evidence of virtual absence of functional labyrinths. In view of the lack of truly definitive vestibular functional tests, this absence, or the unlikelihood of presence, of vestibular function must only be presumed. Baseline postural equilibrium test performances of all except three of the L-D subjects on all of the tests, walking heel-to-toe with eyes open excepted, fell at the 1st percentile level (see Appendix A) in relation to normative standards (8).

The normal group consisted of twenty males which included civilians, Naval officers, and Naval enlisted personnel, 17 to 45 years of age (mean 26.1 years). All were in excellent health. Normal functional labyrinths were evidenced as a result of their normal responses to counterrolling (17), to threshold caloric evaluation (16), and to audiometric testing. Past history of any labyrinthine disturbance was nonsignificant in all. Initial,or baseline, postural equilibrium (ataxia) test performance scores were in most instances average or better (See Appendix B) in relation to normative standards (8).

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*A tenth L-D subject was part of the primary investigation but was not included in the present study because of lack of baseline performance scores.

TESTS*

Test Battery

Only the long version of the Test Battery was administered to the L-D subjects. Apparatus used in this version consists of six rails, each 8 feet long, of varying widths (2-3/4", 2-1/4", 1-3/4", 1-1/4", 3/4", and 1/2"). Three distinct postural tests were given on each of these rails in the following order: 1) walking with eyes open (Walk H/T Test) 2) standing with eyes open (Stand E/O Test), and 3) standing with eyes closed (Stand E/C Test).

Testing of the normal subjects was carried out with the short version. Two of the rails are used in this version: the one 2-1/4" wide and one 3/4" wide. The order of testing was: 1) Walk H/T on the 3/4" rail, 2) Stand E/O on the 3/4" rail, and 3) Stand E/C on the rail 2-1/4" wide.

Clinical-Type Ataxia Tests

Following administration of the Test Battery (Short Version), the normal group participated in two clinical-type tests: 1) standing on each leg for thirty seconds with eyes closed (SOLEC-R, SOLEC-L) and 2) walking a 12-foot line with eyes closed (WALEC).

METHOD

Initial (baseline) testing of all subjects was done in the Vestibular Physiology Laboratory, Naval School of Aviation Medicine. The L-D subjects were tested on several occasions in a practice effects study. The post-sea exposure testing of the normal and L-D subjects alike took place in a warehouse at North Sydney, Nova Scotia. The desirability of simultaneous post-testing of both groups of subjects in the shortest possible time, so as to equate recovery of performance as much as possible along the time axis, was fulfilled by several equivalent sets of Test Battery apparatus (Long and Short Versions). Nine well-trained, experienced examiners (three of them L-D's), acting also as subjects, administered the tests in assembly-line fashion. Both groups were examined in the Post-I period (1/2 hour to 4 hours) and in the Post-II period (16 to 21 hours) following the sea experience; only the normal group was tested in the Post-III period (36 hours).

The stringent body position for all tests was as follows: a) body erect or nearly erect, b) arms folded against chest, c) feet in heel-to-toe position and tandemly aligned (SOLEC Test excepted). Shoes were not removed for the test series. Instructions were given both verbally (to normals) and in writing.

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*Apparatus, administration, and scoring procedures of all the postural equilibrium (ataxia) tests utilized have been described at length in a previous publication (8).

The various tests were scored as follows: the best two of three trials for the Test Battery (Long Version); best three of five trials for the Test Battery (Short Version); weighted scores were used for the SOLEC tests; and the WALEC score was the best two of three trials; i.e., best was the least number of inches of deviation from the line. Maximum scores obtainable on each of the tests were:

Walk H/T Test: (Long Version)--60 (steps) or two perfect five-step trials on each of six rails. (Short Version)--15 (steps) or three perfect five-step trials on the one rail used.

Stand E/O Test and Stand E/C Test: (Long Version)--720 (seconds), representing two perfect 60-second trials on each of six rails. (Short Version)--180 (seconds), or three perfect 60-second trials on the one rail used for each test.

SOLEC: 150 weighted seconds (30 seconds x 5 trials).

WALEC: Number of inches deviation from the line. It should be noted that a major limitation of the WALEC procedure is that, in notably ataxic individuals such as the L-D subjects, the qualitative performance is often more deviant than the individual's score would indicate. Accordingly, the WALEC quantitative scores probably reflected spatial orientation skills more than they reflected ataxia per se.

RESULTS AND DISCUSSION

LABYRINTHINE DEFECTIVE GROUP

The Test Battery (Long Version) performances of the L-D subjects as a group were not adversely influenced by the storm conditions at sea (Table I). Indeed, the mean postural equilibrium test performances of this group were either maintained or they improved immediately following the return to shore, and in the Post-II period the marked improvements over baseline* performances were, in most instances (Walk H/T Test and Stand E/C Test), statistically significant ($P \leq .05$).

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*Baseline scores represent the practiced performances of this group.

Table 1

Effects of Storm Conditions at Sea Upon the Postural Equilibrium Functioning (Test Battery (Long Version) Performances) of a Group of Nine Labyrinthine Defective Individuals

Test Periods	Walk H/T Mean	Walk H/T S.D.	Stand E/O Mean	Stand E/O S.D.	Stand E/C Mean	Stand E/C S.D.
1. Baseline	39.3	9.24	99.4	61.10	25.4	4.92
2. Post-I(1/2 hr-4hrs.)	40.2	8.95	81.7	79.41	27.3	4.76
3. Post-II (16-21 hrs.)	49.4	5.06	148.9	100.3	32.1	6.01
t of diff. 1.& 2.	0.20		0.50		0.78	
t of diff. 1.& 3.	2.71*		1.19		2.44*	
t of diff. 2.& 3.	2.53*		1.49		1.77	

*P $\leq$ .05

VESTIBULAR NORMAL GROUP

The post-sea experience Test Battery (Short Version) and clinical-type ataxia test performance levels of the normal group in comparison with baseline performance are summarized in Table II. Mean performances on four of the tests decreased from baseline level (Walk H/T Test and WALEC Test excepted) within four hours of return to shore. The decrements on three of these tests, Stand E/C, SOLEC-R, and SOLEC-L, were statistically significant (P .05 - $<$ .01). All (except Stand E/C) test performances recovered to baseline level within the Post-II period. Stand E/C Test performance did not fully recover until the Post-III period. Of interest was the finding of immediate post-sea experience improvements in mean performance on the two "dynamic" (walking) tests, Walk H/T and WALEC, amidst performance decrements shown for the four "static" (standing) tests.

There were, however, appreciable individual differences in the effects of the sea experience upon all of the test performances studied. The question of whether or not individual effects and/or "differential" test effects were adequately represented by total group mean effects was put to statistical test by the following procedure: The group was split in half on the basis of baseline performance scores; i.e., on each of the six tests the baseline performances of the ten lowest scoring subjects constituted the "bottom half group" and these were compared with the performances of the "top half group" (the ten remaining subjects) in terms of post-sea performances.

This procedure revealed results (Table III and Figure 1) which are at variance with the total group findings (Table II). The "top half group" showed immediate (Post-I period) performance decrements on each of the six tests, whereas the performances of the "bottom half group" on all tests except SOLEC-R were either maintained or improved slightly to considerably during the post-sea experience test periods.

In dichotomizing the normal group in terms of baseline performance levels, the baseline walking and standing test performances alike were, in effect, predictive of performance decrement and recoverability following the sea experience. Predictability was limited, however, to single tests rather than to any combinations of postural equilibrium (or ataxia) tests, as only 50-70 per cent of subjects who experienced a performance decrement on a given test also experienced decrement on one or more other performance tests.

Results of this study indicate that the postural equilibrium of the L-D subjects as studied by means of the new quantitative ataxia test battery (Long Version) was not adversely influenced by moderate to severe storm conditions at sea experienced some 20-24 hours prior to post-testing. Had it been possible to undertake postural equilibrium testing immediately following cessation of the storm rather than following the 20-24 hours required to reach shore, performance decrement in the L-D's might well have been demonstrated inasmuch as these subjects have been shown to be not immune to experimentally-induced (by rotation) ataxia superimposed upon their characteristic vestibular ataxia (7).

Table II

Effects of Storm Conditions at Sea Upon the Postural Equilibrium Functioning (Test Battery (Short Version) and Clinical-Type Ataxia Test Performances) of a Group of Twenty Vestibular Normal Subjects

	Test Battery (Short Version)						SOLEC					
	Walk H/T		Stand E/O		Stand E/C		Right		Left		WALEC	
Test Periods	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. Baseline	12.8	2.34	32.9	35.25	85.2	55.67	123.3	37.08	122.0	35.61	13.9	11.00
2. Post-I (1/2 hr-4 hrs.)	13.4	1.93	20.0	8.95	33.9	28.22	93.2	48.29	101.5	36.08	10.6	8.42
3. Post-II (16-21 hrs.)	14.0	1.55	35.5	29.58	66.2	53.35	120.1	43.48	127.6	34.64	10.8	7.75
4. Post-III (36 hrs.)					85.3##	58.70						
t of diff. 1.& 2.	0.86		1.55		3.58**		2.16*		1.76*		1.04	
t of diff. 1.& 3.	1.86		0.25		1.07		0.24		0.49		1.00	
t of diff. 2.& 3.	1.06		2.19*		2.33**		1.80		2.27*		0.08	

*P ≦ .05 **P ≦ .01 ##N = 19

Table III

Post-Sea Experience Postural Equilibrium (Ataxia) Test Performances as a Function of the Level (Top-Half vs. Bottom Half) of Baseline Performances in a Group of Normal Subjects

Test Battery (Short Version) and Clinical-Type Ataxia Tests	1. Baseline Mean	S.D.	2. Post-I Period Mean	S.D.	3. Post-II Period Mean	S.D.	Percent Change 1.&2.	t of diff. 1.&2.	Percent Change 1.&3.	t of diff. 1.&3.	Percent Change 2.&3.	t of diff. 2.&3.
					Top Half Group (N = 10)							
Walk H/T	14.6	0.66	13.5	1.75	14.8	0.60	-7.5	1.76	+1.4	0.67	+9.6	2.11*
Stand E/O	50.2	43.11	23.2	8.70	47.9	34.43	-53.8	1.84*	-4.6	0.13	+106.5	2.09*
Stand E/C	135.4	33.92	37.0	30.98	75.6	57.28	-72.7	6.43**	-44.2	2.69*	+104.3	1.78
SOLEC-R	150.0	0.00	109.2	39.16	136.3	28.95	-27.2	3.13**	-9.1	1.42	+24.8	1.67
SOLEC-L	148.3	3.41	106.1	30.79	128.9	33.48	-28.5	4.09**	-13.1	1.73	+21.5	1.50
WALEC	5.0	2.19	10.2	8.24	9.5	8.52	-104.0	1.83*	-90.0	1.53	+6.9	0.18
					Bottom Half Group (N = 10)							
Walk H/T	10.9	1.92	13.2	2.09	13.2	1.78	+21.1	2.43*	+21.1	2.64*	0.0	---
Stand E/O	15.5	4.92	16.8	8.00	23.1	16.05	+8.4	0.42	+49.0	1.36	+37.5	1.05
Stand E/C	34.9	12.46	30.8	24.77	56.7	43.42	-11.7	0.44	+62.5	1.45	+84.1	1.55
SOLEC-R	96.5	36.30	77.1	51.10	103.9	49.18	-20.1	0.93	+7.7	0.36	+34.8	1.13
SOLEC-L	95.6	33.70	96.8	40.87	126.3	35.72	+1.3	0.07	+32.1	1.88*	+30.5	1.63
WALEC	22.7	8.97	10.9	8.58	12.0	6.65	+108.3	2.85**	+89.2	2.87**	-10.1	0.30

* $P \leq .05$ **$P \leq .01$

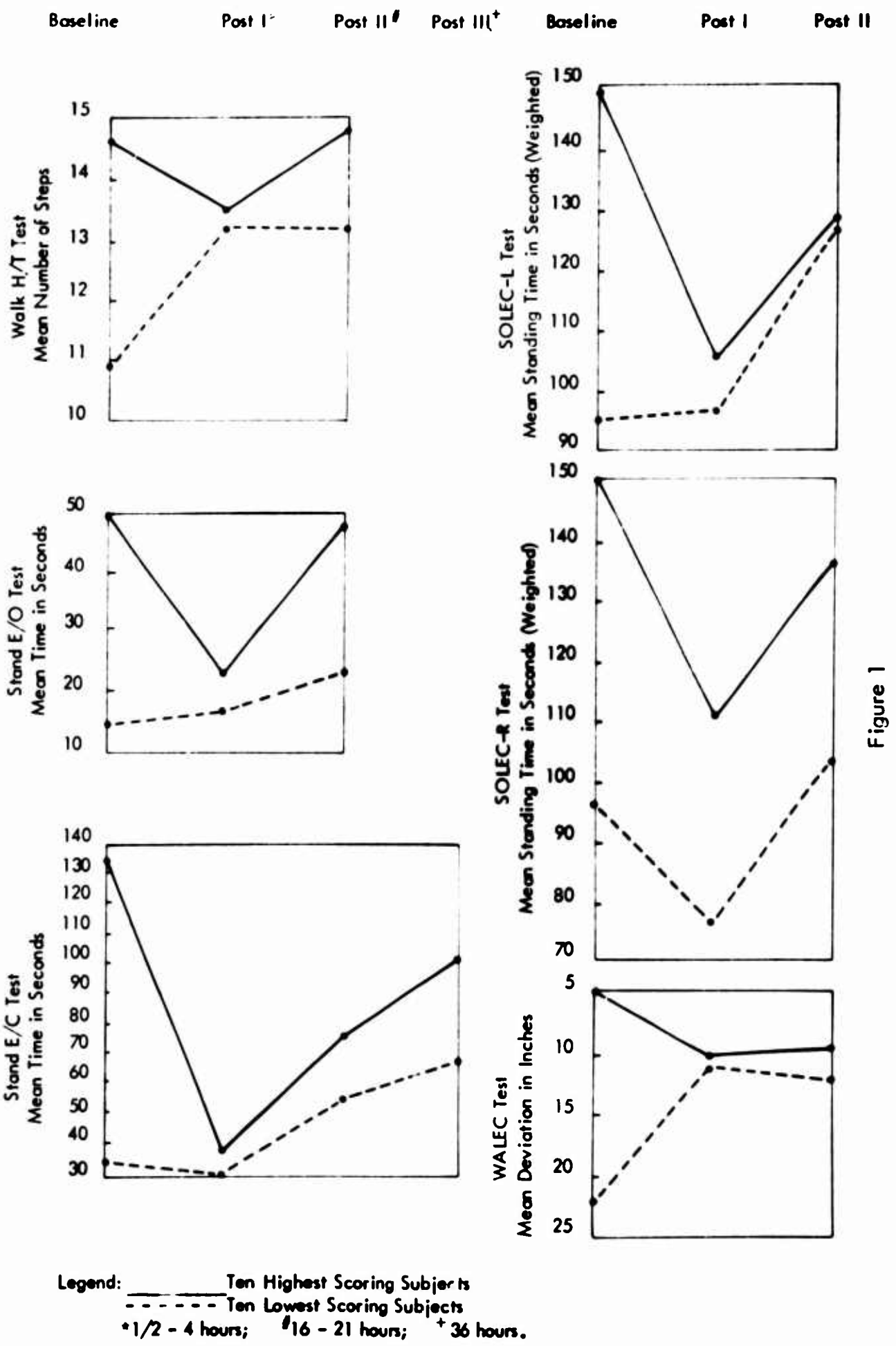

Figure 1

Recoverability from Moderate to Severe Sea Conditions, Reflected by Test Battery (Short Version) and Clinical-Type Ataxia Test Performances, As a Function of Baseline Performances of Normal Males

That not all vestibular normals showed postural performance decrements following the sea experience was found statistically to reflect baseline performance level. Generally, the post-test performances of the initially highest scoring posture test performers were adversely influenced by the sea conditions, whereas, as was found with the L-D subjects, the post-test performances of the initially lowest scoring performers were not. Yet, the lower scoring normals were far from being vestibular ataxic in their initial, pre-experimental performances, and, of course, all of the normals presented pre-experimental evidence of normal vestibular functioning.

Except for the Walk H/T Test, there was no baseline score overlap between the two sub-groups and, in comparison with normative standards (Table IV), the "top half group" scores ranged from the 39th-99th percentiles, whereas in the "bottom half group" the scores ranged from 1st to the 72nd percentile. In view of the pronounced postural effects observed generally in average or better, performers, the finding that several relatively high scoring individuals in the "bottom half group" failed to show performance decrement suggests the possibilities that: 1) in such individuals recovery occurred prior to the much delayed post-testing periods; and/or 2) under conditions of extended practice prior to the experiment all of the normals might have been similarly affected.

Stand E/C performance, in requiring the longest recovery time (36 hours), proved to be the most sensitive indicator in the normals of postural equilibrium dysfunctioning following the sea experience. This finding is consistent with another experiment which disclosed that, as late as 72 hours after cessation of rotation in the Pensacola Slow Rotation Room at 10 RPM for a period of 12 days (10), the Stand E/C performances of the vestibular normal (sensitive) subjects had not recovered to pre-experimental, or baseline, level, whereas the performances on the two visual tests, Walk H/T and Stand E/O, had not only recovered but were also improved. Also of interest in the present study was the finding that the clinical-type ataxia tests proved to be as, or nearly as, sensitive to the sea experience as the Test Battery (Short Version).

Stand E/C performance in the L-D's, in contrast with the normals, was the least influenced by storm at sea conditions, which is a finding consistent with results of the prolonged rotation experiment (7). Among the sub-tests constituting the Test Battery, standing eyes closed test performances best differentiated vestibular ataxic (labyrinthine defective) individuals from individuals found to be free of vestibular pathology.

The predictability of performance decrement attributable to vestibular stimulation directly or indirectly as a function of baseline performance on single tests only, rather than on any combinations of tests, supports previous observations (7,8) that such test-defined postural equilibrium dysfunctioning may not be generalized but rather that such functioning must be considered unique in its manifestations in a given individual. Stated another way, a given subject's performance decrement was test-dependent, or specific, and not test-series-dependent, or general. The significantly overlapping yet highly varying aspects of postural equilibrium functioning tapped by the present series of tests in terms of low to moderate intertest correlations (8) argues strongly for the continued utilization of a multifaceted test battery in lieu of any as yet known precise definition of postural equilibrium functioning-dysfunctioning by any single test.

Table IV

Baseline Postural Equilibrium Test Score Differences and Their Percentile Equivalents Between the Top Half and the Bottom Half of the Group of Twenty Normal Subjects

	Top Half Group		Bottom Half Group	
Postural Test	Score Range	Percentile Range	Score Range	Percentile Range
Walk H/T	13 - 15	60th - 99th	7 - 13	7th - 60th
Stand E/O	24 - 170	47th - 99th	8 - 23	1st - 43rd
Stand E/C	83 - 180	47th - 99th	14 - 58	3rd - 35th
SOLEC - L	141 - 150	39th - 99th	60 - 140	4th - 72nd
SOLEC - R	150	99th	35 - 146	2nd - 43rd
WALEC	10 - 2	44th - 95th	43 - 11	1st - 39th

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APPENDIX A

APPENDIX A

Test Battery (Long Version) Baseline (Unpracticed) Scores and Their Percentile Equivalents in the Group of Labyrinthine Defective Subjects

		Test Battery (Long Version)										
		Walk H/T		Stand E/O		Stand E/C		SOLEC-L		SOLEC-R		WALEC
Subject	Age	Score	%-tile	Score	%-tile	Score	%-tile	Score	%-tile	Score	%-tile	Score
DO	43	25	1st	45	1st	29	1st	13	1st	9	1st	U.t.P.*
GR	47	39	1st	114	1st	22	1st	15	1st	11	1st	U.t.P.
GU	21	26	1st	36	1st	20	1st	12	1st	10	1st	U.t.P.
HA	30	35	1st	51	1st	23	1st	10	1st	16	1st	U.t.P.
JO	34	40	1st	58	1st	31	1st	14	1st	17	1st	U.t.P.
MY	24	40	1st	110	1st	23	1st	12	1st	10	1st	U.t.P.
PE	33	48	10th	85	1st	19	1st	18	1st	17	1st	U.t.P.
ST	20	46	7th	162	1st	28	1st	12	1st	12	1st	U.t.P.
ZA	21	55	50th	234	1st	34	1st	24	1st	34	2nd	U.t.P.

*Unable to perform. All L-D subjects failed to meet the criteria of traversing 12-foot length on floor with eyes closed for a scorable trial despite repeated practice.

APPENDIX B

Appendix B

Test Battery (Short Version) and Clinical-Type Ataxia Test Baseline Scores and Their Percentile Equivalents in the Group of Vestibular Normal Subjects

		Test Battery (Short Version)											
		Walk H/T		Stand E/O		Stand E/C		SOLEC-L		SOLEC-R		WALEC	
Subject	Age	Score	%-tile	Score	%-tile	Score	%-tile	Score	%-tile	Score	%-tile	Score	%-tile
BE	38	10	25th	12	7th	37	23rd	106	20th	150	99th	17	16th
MC	37	7	7th	8	1st	140	65th	150	99th	97	15th	10	44th
KE	26	10	25th	10	4th	155	70th	150	99th	52	4th	6	66th
CA	29	15	99th	28	56th	83	47th	150	99th	150	99th	11	39th
RI	41	13	60th	21	37th	131	63rd	86	11th	128	26th	3	90th
UP	40	9	15th	11	6th	47	30th	123	30th	150	99th	3	90th
TR	45	13	80th	24	80th	36	53rd	140	72nd	35	2nd	20	11th
VA	25	15	99th	81	91st	169	79th	150	99th	122	20th	2	95th
DA	22	14	70th	23	43rd	38	24th	57	3rd	146	43rd	18	14th
AL	18	12	40th	33	63rd	180	99th	114	24th	150	99th	25	7th
DE	18	10	25th	28	56th	41	26th	60	4th	62	7th	4	81st
DO	18	15	99th	44	74th	58	35th	32	2nd	74	10th	34	1st
JO	22	15	99th	43	74th	17	7th	150	99th	150	99th	43	1st
OV	18	13	60th	17	25th	27	15th	142	40th	150	99th	5	76th
PO	19	12	40th	14	13th	112	57th	150	99th	150	99th	7	60th
ST	19	15	99th	170	99th	180	99th	150	99th	150	99th	16	19th
TOD	19	13	60th	19	30th	87	48th	109	22nd	150	99th	5	76th
TOR	18	15	99th	27	54th	34	20th	129	34th	130	28th	24	8th
WH	17	15	99th	24	47th	117	59th	141	39th	119	19th	19	14th
SA	33	14	70th	20	33rd	14	3rd	150	99th	150	99th	5	76th

ERRATA SHEET NSAM - 935 Gummed back paper, paste over Page 3: 2nd and 3rd paragraphs.

Walk H/T Test: (Long Version)--60 (steps) or two perfect five-step trials on each of six rails. (Short Version)--15 (steps) or three perfect five-step trials on the one rail used.

Stand E/O Test and Stand E/C Test: (Long Version)--720 (seconds), representing two perfect 60-second trials on each of six rails. (Short Version)--180 (seconds), or three perfect 60-second trials on the one rail used for each test.